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PECULIARITIES OF MOTION OF TINY METEOR BODIES

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SUMMARY

On the basis of earlier observations an annual cycle of radar measurements of individual radiants and velocities of meteors was conducted at the Khar'kov Polytechnical Institute. These data, coupled with similar observations by other authors, led to a series of conclusions concerning the eccentricity, the perihelion distance, the orbit inclination of tiny meteor bodies. Two new types of orbits have been revealed. They were found to be important for the study of the origin and the evolution of meteor matter.

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Between November 1959 and December 1960, a yearly cycle of radar measurements of individual radiants and velocities of meteors was conducted at the Khar'kov Polytechnical Institute. Measurements of velocities were conducted by the pulse-diffraction method [1] ; those of radiant coordinates — by spaced reception of radiowaves scattered on the forming meteor wake [2]. The radar station (RLS) with wavelength $\lambda = 8$ m was utilized. The apparatus and the method of processing of operations are described in [3, 4] . The root-mean-square error of single velocity observation is $\pm$ 2 km/sec, that of the radiant coordinate $\pm$ 2. 5. Calculated with the aid of a computer were 12,500 orbits of meteor bodies, generating meteors brighter than about + 7 m.

Earlier similar measurements were conducted only by Davis and Hill [5] , who obtained 2,474 orbits for meteors + 5 — +7 stellar magnitude. The orbits of such tiny meteor bodies differ substantially from those of coarse meteor bodies, generating bright photographic meteors (brighter than about 0 of stellar magnitude). These discrepancies may be explained by the difference in the character of motion of various types of meteor bodies in the solar system, as well as by the different selectivity of radar and photographic methods of observation. During the analysis of the observation material particular attention was given to the selectivity effect of the radar method. In order to pass from the measured distribution of orbits to the true one, it is

* OSOBENNOSTI DVIZHENIYA MELKIKH METEORNYKH TEL

necessary to take into account the following factors: a) the "geometric factor" $1/P_1$, which characterizes the relative observability of meteors with different radiant declinations, determined by the geometry of antenna system's radiation pattern' b) the "physical factor" $1/P_2$, characterizing the relative perceptibility of meteors with different velocities, determined by the dependence of the ionization factor β, the vaporization heights h and the distribution of the linear electron density along the meteor wake on the initial mass M_0 and the velocity v_0 of the meteor body, and also by the dependence of the initial radius r_0 of the ionized wake on v_0 and h; c) the "astronomical factor" $1/P_3$, which characterizes the dependence of the probability of the encounter with the Earth on the parameters of particle orbit.

The astronomical factor influences the results of ground observations of meteors by any method. The quantity P_3 was computed by Opik [6] :

$$P_3 = \frac{v_g \sin i}{v_0^2}\left[2 - \frac{1}{a} - a\left(1 - e^2\right)\right]^{1/2}, \tag{1}$$

where v_g is the geocentric velocity of the meteor; i is the orbit inclination; a is the major semi-axis; e is the eccentricity.

The method of computation of the geometric factor has been described in [7] . The value of P_1 is mainly dependent upon the declination of meteor radiant δ and is less dependent on v_0. The values of $P_1(\delta, v_0)$ for the radar station, applied at Khar'kov Polytechnical Institute, are compiled in Table I for antenna system orientation to the East and for meteors with velocities v_0 = 40 km/sec.

TABLE I

δ	$-20°$	$0°$	$+20°$	$+40°$	$+60°$	$+80°$
$1/P_1(\delta, v_0)$	0,3	0,6	0,9	1,6	2,5	3,4

The maximum value of the power of a signal scattered on the meteor wake with $\alpha < 10^{12}$ electron/cm^3 [3] is

$$P_r = \frac{P_t G^2 \lambda^3 \alpha_{\text{эф}}^2}{32\pi^2 R^3}\left(\frac{e^2}{mc^2}\right)^2, \tag{2}$$

where

$$\alpha_{\text{эф}} = \alpha e^{-(2\pi r_0/\lambda)^2}\,\frac{1 - e^{-\Delta\sqrt{2}}}{\Delta\sqrt{2}}; \quad \Delta = \frac{8\pi^2 D\sqrt{R}}{v_0 \lambda^{3/2}}; \tag{3}$$

P_1 is the transmitter power; G is the antenna system's directivity factor; e, m are respectively the charge and the mass of the electron; c is the speed of light; D is the ambipolar diffusion coefficient; T is the remoteness. The effective response of the radar station, characterized by the minimum value $\alpha_{\text{эф}}$ of the wakes that may be detected in the direction of the maximum radiation, constituted in our case $\alpha_{\text{эф}}^{min} = 2 \cdot 10^{10}$ electron/cm.

The vaporization height and the distribution of ionization along the meteor wakes generated by meteor bodies with various masses and velocities, have been considered by V. N. Lebedinets [7] . The initial radius of ionized meteor wakes was obtained in [3] .

Taking into account the random position of the mirror reflection point on the wake, the probability of detection of the wake formed by a meteor body with a given mass, M_0, velocity v_0 and the zenithal distance of the radiant z, is proportional to the length $l(M_0, v_0, z)$ of the wake, over which $\alpha_{eff} > \alpha_{eff.}^{min.}$. The relative perceptibility of meteors with various v_0 and z is

$$\frac{1}{P_2} = \int_0^{\infty} l(M_0, v_0, z)\, n(M_0)\, dM_0, \qquad (4)$$

where $n(M_0) = M_0^{-8}$ is the distribution of meteor bodies by masses. The values of $P_2(v_0)$ at cos z = 2/3, $\alpha_{eff}^{min} = 2 \cdot 10^{10}$ el/cm, $\lambda = 8$ m and s = 2, are compiled in Table II.

TABLE II

v_0, км/sec	15	20	30	40	50	60	70
$1/P_2(v_0)$	0,06	0,40	1,10	1,00	0,68	0,36	0,20

Ascribing to every meteor a "cosmic weight" $P = P_1 \cdot P_2 \cdot P_3$, we may pass from the measured distribution of orbits to a distribution for the entire complex of meteor bodies with masses greater than a certain minimum magnitude, whose orbits have perihelion distances $q \leqslant 1$ a. u. and aphelion distances $q' \geqslant 1$ a. u.

The distribution of orbit elements for tiny meteor bodies, obtained by the authors, is plotted in Fig. 1. For comparison we shall make use of photographic determination of orbits of meteors brighter than +3 stellar magnitude [8] and of 144 meteors brighter than the 0 s. m. [9].

Major Semiaxis. — In meteor bodies, generating meteors brighter than 0 stellar magnitude, the values of a, most frequently encountered, are of the order of 5 a. u. A great number of orbits are close to parabolic. There is not a single orbit with $a \leqslant 1$ a. u. In meteors of 0 - 3 stellar magnitude orbits with $a \approx 3$ a. u. are the ones most frequently encountered. Orbits close to parabolic are somewhat less frequent. Nearly 6% of orbits have $a < 1$ a. u. For meteors of +5 — +7 stellar magnitude, the orbit distribution maximum along 1/a shifts to the region of still smaller values $a \approx 2$ a. u. Nearly 20% of orbits have $a < 1$ a. u. The number of orbits close to parabolic is substantially smaller than in the case of photographic meteors. Therefore, systematic decrease in the dimensions of the orbits takes place as meteor body masses decrease.

Eccentricity. - The photographic and radar measurements provide nearly an identical distribution of orbit eccentricities of various-type meteor bodies.

Perihelion Distance. - For tiny meteor bodies the distribution function increases almost monotonically at decrease of q from 1. 0 to 0. 05 a. u. In the case of coarser particles, generating photographic meteors, a nearly monotonic decrease of the distribution function takes place at q decrease from 1 to zero. The mean perihelion distance of tiny orbits of meteor bodies generating meteors of $+5 — +7^m$, is found to be almost twice smaller than for coarser meteor bodies generating meteors of $0 — 3^m$.

Orbit Inclination. - Radar observations provide for tiny meteor bodies an almost uniform orbit distribution by i. Two wide maxima take place, at $15^o < i < 65^o$ and $120^o < i < 160^o$, and a minimum at $i \approx 90^o$. In case of photographic meteors, most of the orbits have small inclination, $i < 30^o$. A minimum for the distribution function is observed at i near 90^o, and a certain increase is noted at $110^o < i < 150^o$.

In the case of coarse meteors, the distribution by is different for orbits with great and small eccentricities. At $e >$ o. 8, the orbits are distributed nearly uniformly by i in the interval $30^o < i < 180^o$. At $e < 0.7$, nearly all orbits have small inclinations ($i < 30^o$). Such an increase of concentration toward the ecliptic as the eccentricity decreases is particularly characteristic for orbits of the coarsest meteor bodies generating meteors brighter than 0 of stellar magnitude. Of the 144 orbits brought out in the Whipple catalogue [9] , only one hits the region $e < 0.7$ and $30^o < i < 150^o$. For meteors brighter than +3 stellar magnitude there are less than 10%of such orbits. For meteors brightern +7 s. m., there are more than 30% of such orbits.

From photographic observations, two fundamental types of orbits of coarse meteor bodies are known: a) orbits similar to those of short-period comets (for which relatively small dimensions, $a \lesssim 5$ a. u. and small inclinations, $i < 30^o$, are characteristic); b) orbits similar to those of long-period comets (for which comparatively great dimensions and arbitrary inclinations are characteristic). The fundamental radar observations of meteors revealed still two more basic types of orbits characteristic of tiny meteor bodies; c) orbits with $e < 0.7$ and $30^o < i < 165^o$; d) the main mass of tiny meteor bodies moves along elongated orbits with $e > 0.7$ which are close in their shape to orbits of short-period comets, but differ from them by significantly smaller perihelion distances and dimensions ($a < 3$ a. u.). From photographic observations, such orbits were obtained for a few meteor streams (Geminides, Aquarides and others), for which no parent comets were revealed.

The detection of two new types of orbits for tiny meteor bodies c) and d) has a great significance for the study of the origin and of the evolution of meteor matter. Two groups of cometary orbits are interrelated, inasmuch as the perturbations of Jupiter may transfer the comets from type b) to type a) orbits. The orbits of the types c) and d) are almost never encountered among the well known coarse bodies of the solar system and they are not derivatives of either type a) or asteroid orbits.

Apparently, a significant number of tiny meteor bodies are formed on orbits of very large dimensions. Under the effect of deceleration forces (Pointing-Robertson effect, drag of the interplanetary medium, etc.), the major semiaxes and the eccentricities of the orbits decrease gradually and so much the faster that the mass of the meteor body is smaller. As was shown by Öpik [6] for small i, the meteor bodies, generating meteors brighter than +9 s. m. will then be captured by Jupiter. At great i, the "Jupiter barrier" may be passed also by meteor bodies with somewhat greater masses. The presence of type c) orbits at meteor bodies generating meteors of +5 — +7 s. m.

and their absence in coarse meteor bodies may be explained by this mechanism.

The presence of a large number of meteors with orbits of the type d) must appear in the solar system. Because of the nearness to the Sun in the perihelion, the lifetime of comets on type d) orbits is very small. It is apparently significantly shorter than the lifetime of meteor streams generated by such comets.

* * *THE END* * *

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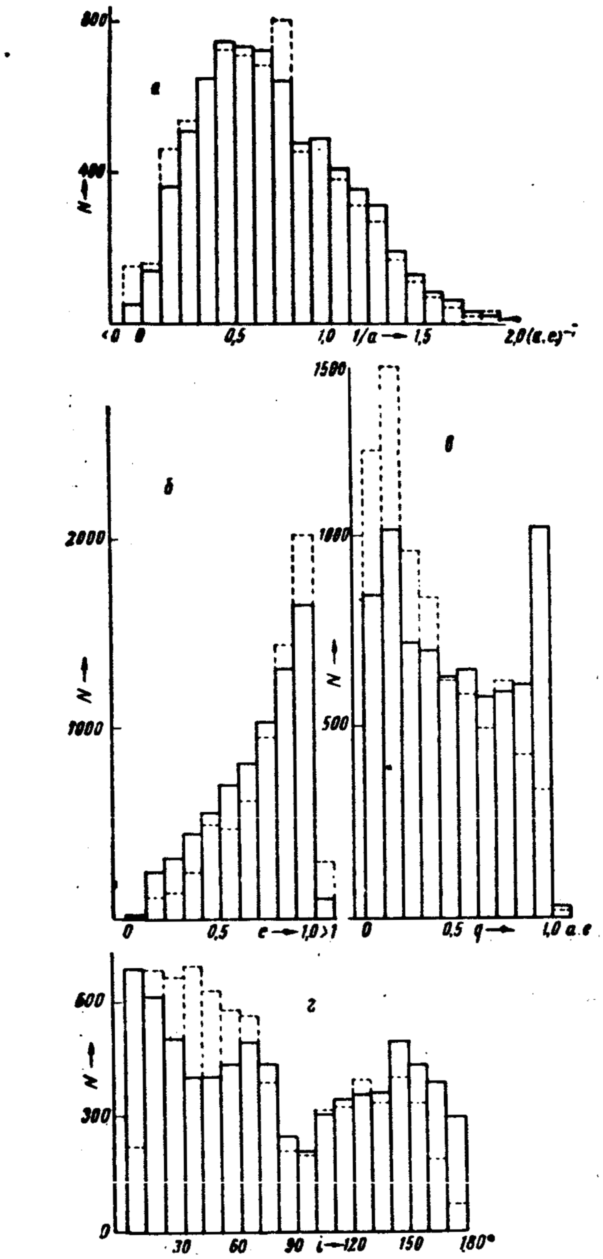

Fig. 1. - Distribution for orbits of meteor bodies
a. - of the great (major) semiaxes
b. - of the eccentricities
c. - of perihelion distances
d. - of inclinations
The visible distribution is plotted by a solid line, the corrected one for observation selectivity - by a dashed line.

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